Factors of affecting the spring back of compressed *Paulownia* wood

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Abstract In order to increase its hardness and gravity as well as dimension stability, the technology of hot-compressing on *Paulownia* wood was studied. The main factors of affecting the spring back of the compressed *Paulownia* samples were discussed. It was discovered that every factor in the experiment had obvious effects on wood hardness and dimension stability of compressed wood. When the MC (Moisture Content) of experimental specimens was 13.89%, it was useful to spray water on the surface of samples before hot pressing. The best result was the recovery of compression set could decrease from 90.69% of untreated wood to 45.51% of soaking specimens into PF (Phenol Formaldehyde) water solution. The hot pressing time was 8 min at 190 ℃.
Key words: *Paulownia* wood, Compression, Soaking, Recovery of compression set

Instruction

Paulownia genus (*Paulownia sieb.* Et Zucc.) is originated from Southeast Asia and introduced into Europe, North America and Australia for plantation (Giebeler 1983). There are 9 species and 2 varieties in this family (Zhu 1981). *Paulownia* tree is one kind of growing fast timber in China with a broad distribution in all the country. The main timber producing area is in northern plain of China in which the *Paulownia* is planted with crops. It is well accepted by Chinese, Japanese, Korean due to its beautiful grain and lovely luster as well as its stable dimension. The cross breeding hybrid *Paulownia* trees grow fast, when they become 10~15 years old, the trunks of the trees are about 5 m high with a bread diameter of 40 cm (Chen 1993). There are several defeats such as soft quality and low strength for this wood, because of its natural shortcoming and growing fast (Chen 1983). In order to overcome the soft quality and increase the mechanic properties, the *Paulownia* samples treated in different conditions were compressed in different temperature and time. The recovery of compression set caused by different treatments and hot pressing parameters will be discussed in this paper.

Researchers are searching an effective method to stabilize the dimensions of compressed wood. Due to the moisture content being an important factor of affecting wood dimensions, many methods were studied by the scientists between Kyoto University in Japan and the Forest Products Laboratory in the United States. The range was from bulking the cell wall with simple aqueous sugar solutions to chemical reactions with the cell wall polymer. Masafumi Inoue (1993) reported an experiment that one group of the specimens of (*Cryptmeria japonica* D. Don) was steamed and then compressed, and another group was compressed and then steamed. He found that the compressed wood steamed for one min at 200 ℃ or 8 min at 180 ℃ had no recovery of set, and it had large increases in hardness, minimum decreases in mechanical properties, and slight darkening.

In 1946 Stamm *et al.* reported a method of dimensional stabilization of wood that based not on the use of chemical but on the use of heat alone. The experiments were done between 160 ℃ and 280 ℃. They found that the dimensional stability got great improvement.

Hillis *et al.* (1987) also worked to stabilize wood by a heating process. They found that a minimum heating result of 2 h at 100 ℃ plasticized the hemicellulose-lignin matrix to affect additional stability. To minimize thermal degradation of the wood, they suggested that the wood be presteamed or preheated for as short a period as possible. Hillis (1984) also gave a review of the literature in this area.

Burmester (1973) found that under optimum moisture content, heat, and pressure, deformation caused by moisture swelling was reduced 75% for oak heartwood, 60% for beech sapwood, 55% for pine sap-

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wood and heartwood, and 52% for spruce.

Giebeler (1983) found swelling decrease of 50% to 80% when beech, birch, poplar, pine, and spruce were heated at 180℃ to 200℃ in an inert gas atmosphere from 0.8 MPa to 1.0 MPa.

Iuoue *et al.* (1991) found that dimensional stability could be improved by either steaming or heating while the wood was in a compressed state.

The reports about *Paulownia* compression are not found. The purpose of this paper is to increase the hardness of compressed *Paulownia* wood under the treatments of different MC and several concentrations of PF (Phenol Formaldehyde) solution in different hot pressing time and temperature. The dimension recovery of the compressed specimens soaked in water was investigated.

Specimens and instruments

Paulownia lumbers dried in the air were random cut into the specimens of 45 mm × 25 mm × 15 mm (Longitudinal by Adial by Tangential). Each group of samples contains 4 specimens connected together in the board. Three of them were as testing specimens; the other one was comparative specimens. The three testing specimens after hot press were separately used in swelling experiment in the equivalent moisture content (EMC) room, in soaking experiment into the normal water and in the comparative experiment in the air. Specific gravity of *Paulownia* was 0.259 6 g/cm^3, the moisture content is 4.13%. The press of 50 cm × 50 cm is heated by steam.

Experimental design

Four factors were designed to experiment in order to watch the effects of them on the dimension recovery of compressed specimens. They are separately MC group, temperature group, time group, and PF (Phenol Formaldehyde) group. Every specimen of all groups were weighed and measured before and after experiment.

MC group (Ⅰ)

There are six kinds of treated specimens in this group. They are ⅠA, ⅠB, ⅠC, ⅠD, ⅠE and ⅠF. ⅠA is untreated specimens whose MC is EMC in the air. IB, IC, and ID were separately in EMC room of 50%, 65%, 90% for 17 days at 24℃ for 30 h. The specimens of ⅠE were soaked in the normal water at 24℃ for 30 h, then weighed. The soaked specimens were put into sealed plastic bags for 6 h. ⅠE is the specimens sprayed by water on the surface before hot pressing (Table 1). The time is 5 min at 190 ℃ for hot pressing in this group.

Temperature group (Ⅱ)

Three kinds of air seasoned specimens of ⅡA, ⅡB and ⅡC were separately compressed at 150℃, 170 ℃ and 190℃ for 5 min.

Table 1. The moisture content of MC group (Ⅰ) %

Name	Kinds of treated specimens					
	ⅠA	ⅠB	ⅠC	ⅠD	ⅠE	ⅠF
MC	4.13	6.91	9.15	13.89	60.54	Spraying

Time group (Ⅲ)

The air dried specimens of ⅢA, ⅢB, ⅢC and ⅢD were separately compressed at 190℃ for 2, 5, 8 and 11 min.

PF group (Ⅳ)

There are four kinds of specimens of ⅣA, ⅣB, ⅣC and ⅣD for experiment in this group. ⅣA is untreated natural seasoned specimens for comparative test. ⅣB, ⅣC and ⅣD were separately soaked in PF water solution of 10%, 20%, 30% concentrations for 6 d, then they were seasoned in the air at 24 ℃ for 8 d. The solid content of PF is 50%.

All the experimental specimens were compressed from 15 mm to 9 mm controlled by thick ruler. They would be weighed and measured after hot pressing.

Percentage of compression set (C) was calculated by $C = \frac{T_o - T_c}{T_o} \times 100\%$

Where T_o is the air dried thickness before compression, and T_c is the thickness after compression:

Recovery of compression set (R) was calculated by

$$R = \frac{T_R - T_C}{T_O - T_C} \times 100 \ \%$$

Where T_r is the thickness after specimens soaked in normal water. The specimens after compressed were soaked into common water for 10d. During the first hour in the water, the thickness of specimens (T_r) was measured for every 15 min. Then they were measured one time every hour at the beginning 8 h. Then they were measured for one time every day.

Results and discussion

The results of Fig. 1 show that the treated specimens in different EMC room had great difference in the recovery of compression set, the percentage of compression set which decreased with the increase of the MC of specimens. Untreated samples (ⅠA) with MC of 4.13% sprang back very fast when they soaked in the water at the beginning 60 min, and kept this maximum C at the experiment time. The sprayed

specimens (I E) that the moisture content (MC) of which is below saturation point got best dimension stability. There was no much difference in percentage of compression set (*C*) between I B and I C, just 0.97%. When the MC is 13.8%, the percentage of compression set (*C*) of I D is 20.49%, less than that of I C, but is higher than that of green wood I E. The best MC of specimens is 13.89% because the quality of I D surface is better than that of I E.

At the initial one-hour of soaking into water, the recovery of compression set (*R*) of I F sprayed by water on their surface before hot pressing is the minimum among all kinds of samples. When soaking is going on, the specimens of I F began to spring back fast. This phenomenon means that water in the surface of wood took an important part in the harden specimens. The specimen's surface of IF was shaped a hard and density and stable face that is reluctant to the water. In the same time, the internal of the specimens kept normal condition. When specimens soaked into water for one hour, the water enters across its hard surface and goes into the normal tissue of wood; the specimens begin to recovery from compression set.

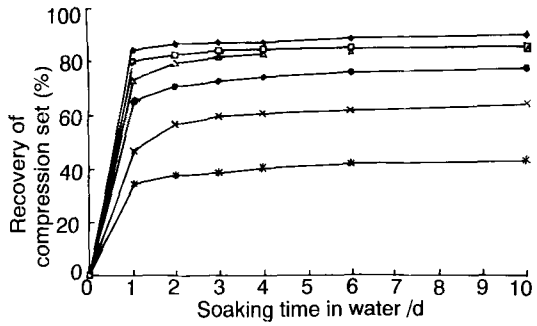

Fig. 1. Recovery variation of compressed wood influenced by MC

--◆ -- I A; -- □-- I B; --△-- I C; --x -- I D; --* -- I E; -- ●-- I F

Water in the wood promotes the thermoplasticity of wood as the molecule of water helps the plasticity of semicellulose and lignin. When it enters the amorphous regions, the water damages the fixation between crystalliferous regions and amorphous regions. The stable amorphous regions where cellulose stays provide no effect on the increase of thermo plasticity of wood (Lu 1993).

The effect of the temperature change of press on the recovery of compression set was observed in this group. There was slight change of *R* due to the change of the hot pressing temperature. Fig. 2 shows the decrease of recovery of compression set (*R*) with the temperature increase in the beginning 2 h of soaking experiment. From then, there was no big difference in *R* between 150℃ and 170℃. When the temperature reached 190℃, the dimension stability of II C got some increase, *R* of II C decreased 3.89%, which was less than that of II B. So, the suitable temperature of hot pressing is 190℃.

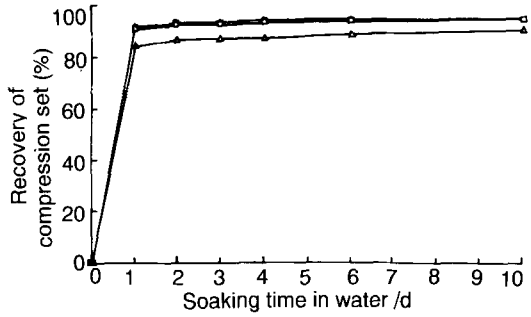

Fig. 2. Recovery variation of compressed wood influenced by hot pressing temperature

--◆ -- II A; -- □-- II B; --△-- II C

It is shown that the longer of hot pressing time is, the lower of the percentage of compression set (*C*) for compressed wood is in Fig. 3. When time is 5 min, the *R* of IIIB is a little different from that of IIIA, just 1.05%. When time increased to 8min, the *R* of IIIC decreased 9.42%, which was less than that of IIIB. When time goes up to 11 min, the *R* of IIID gets a few increase, but also gets dark surface. The best hot pressing time is 8 min (Fig.3).

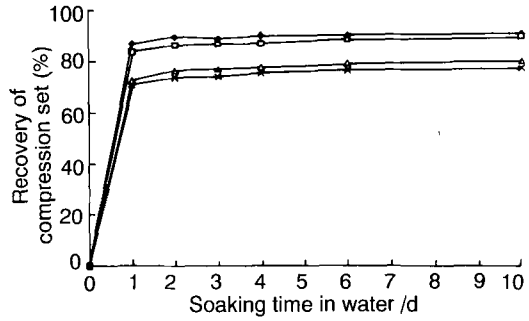

Fig. 3. Recovery variation compressed wood influenced by hot pressing time

--◆ -- IIIA; -- □-- IIIB; --△-- IIIC; --x -- IIID

It is discussed in this group that the concentration of PF solution affected the recovery of compression set. Comparing with untreated specimens of IVA, all the specimens treated by PF solution got obvious promotion in dimension stability. Table 2 tells us that *R* decreased from 90.69% of IVA to 51.06% of IVB and remained down with the increase of PF concentration. The treated specimens got better waterproof ability are shown in Fig. 4. It is obvious in Fig. 5 that the increase of PF concentrations brought about great change; *R* of IVC just decreased 5.08%, which was less than that of IV B. The resin treatment

caused dark red appearance of wood. Due to water-absorption capacity of PF, It is more difficult to dry the wood when the concentration of PF solution increased. At same drying period, ⅣC bulged slightly, ⅣD seriously bulged but ⅣB didn't show this action. Table 3 also shows this disadvantage due to the high steam pressure when hot pressing, the specimens with higher MC got more serious spring back. The percentage of compression set (*C*) of ⅣB is 35.34%, and that of ⅣD is just 14.24%. It is obtained from this experiment that 10% concentration of PF solution is reasonable and economic. When wood is compressed, the wall of cell began soft and the cell became deformed due to the heat, humidity and force, the resin entered into amorphous regions of cell wall mixed with cellulose, semi-cellulose and lignin and keep the deformed shape stable. Because most of hydrophilic hydroxyls had reacted with the molecules of resin, the treated wood showed strong waterproof.

Table 2. The recovery of compressed specimen (*R*) %

Group	Kinds of treated specimens					
	A	B	C	D	E	F
Ⅰ	90.69	86.29	85.32	64.83	43.78	78.21
Ⅱ	94.59	94.58	90.69			
Ⅲ	91.74	90.69	81.27	78.42		
Ⅳ	90.69	51.06	45.18	55.18		

Table 3. The percentage of compression set (*C*) %

Group	Kinds of treated specimens					
	A	B	C	D	E	F
Ⅰ	35.96	37.48	38.73	38.27	23.39	36.83
Ⅱ	35.73	35.79	35.96			
Ⅲ	35.30	35.96	35.99	35.67		
Ⅳ	35.96	35.34	20.40	14.24		

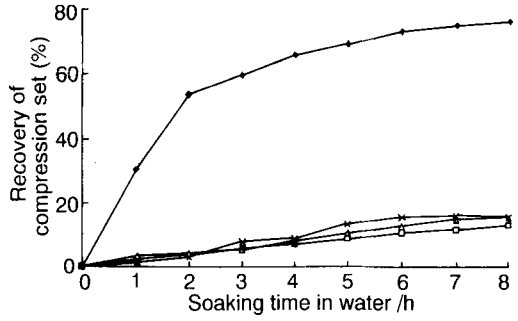

Fig. 4. Recovery variation of compressed wood in the initial 8 h of soaking in water

--◆ -- ⅣA; -- □-- ⅣB; --△-- ⅣC; --x -- ⅣD

Conclusions

The recovery of *Paulownia* compressed wood decreases with the increase of the MC of the specimens. The best MC of them is 13.89%. When the MC of the wood is higher than the saturated point, bulging of the specimens and darkening will occur after hot pressing. The treatment of spraying water on the surface o specimens is helpful to *Paulownia* surface density and dimension stability.

Temperature takes an active part in *Paulownia* wood thermal plasticity. The most suitable temperature is 190℃ for increase of the wood dimension stability.

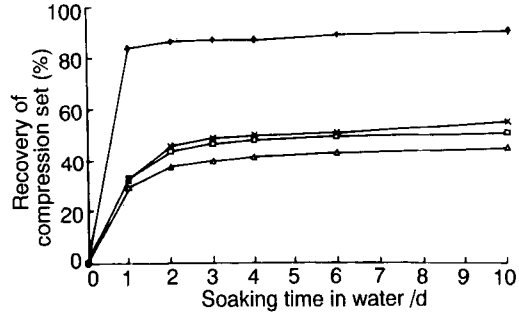

Fig. 5. Recovery variation of compressed wood influenced by the concentrations of PF solution

--◆ -- ⅣA; -- □-- ⅣB; --△-- ⅣC; --x -- ⅣD

The *R* of specimens will decrease and the dimension stability of compressed wood will increase when hot pressing time become longer. The best pressing time is 8 min with obvious decrease of the *R* and ideal appearance quality.

The specimens soaked in PF solution will vastly increase the stability of compressed *Paulownia* wood. There are few effects on the *R* of specimens when the concentrations of PF increase. The suitable and

economic concentration is 10%.

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